eliminating fire, reducing felling and skidding injuries, favoring low-origin sprouts in hardwood cleanings, cutting defective trees in partial-cutting operations, controlling dwarf mistletoe, and by making prompt salvage in stands that have been heavily damaged by fire, wind, or ice.

By maintaining suitable density in stands until the lower tree trunks are cleared of branches, or by artificial pruning in the more open stands, the incidence of heart rot attacks that develop through dead branches and branch stubs can be considerably reduced in young stands of a number of important western conifers. Defects can also be reduced in eastern white pine and scarlet oak by early pruning.

In eastern and southern softwoods, a cutting age up to 80 years will avoid serious rot losses unless the stands are badly damaged. If fire-scarred pines or otherwise defective pines are removed during partial cuts, even longer rotations would be fairly safe from the decay standpoint for this group. In most eastern hardwoods that are not stump sprouts, cutting ages can be raised to more than 100 years with little loss from decay where the stands are undamaged. Many of the western conifers can be grown to even greater ages without serious decay.

The heart rots that develop through the roots, as in the case of many of the spruce, fir, and pine butt rots, will never be entirely eliminated. Where they are known to be common in a stand, however, cutting can be done early enough to minimize the loss, and in such a way that the residual stand will not suffer undue breakage or windthrow as a result of the decay.

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James W. Kimmey, *pathologist in the same Division, has for the past 20 years conducted research in forest pathology in the West. His territory has included the entire area west of the Rocky Mountains, and some investigations have taken him into western Canada as well. Dr. Kimmey is a graduate in forestry of Oregon State College and Yale University.*

BREEDING AND SELECTING PEST-RESISTANT TREES

RUSSELL B. CLAPPER, JOHN M. MILLER

Genetics has given us a good new tool to use against the diseases and insects of trees—the selection and breeding of trees for resistance to pests. It is a long job. The time that a tree crop takes to produce seed and to mature exceeds the span of a human generation. Natural forces, aided now and then by man, have determined through the ages which forest species should survive, and these are the species with which the forester, the geneticist, and the forest pathologist now work.

Epidemics of introduced parasitic fungi stimulated interest in the development of healthier trees. Forty years ago the Department of Agriculture employed Walter Van Fleet to breed chestnut trees that would resist the introduced blight fungus. Since then several agencies have taken up the work of breeding and selection, for the most part to obtain vigorous, fast-growing specimens for lumber and other products. More recently, greater emphasis has been placed on develop-

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ing trees resistant to particular fungus and virus diseases. The development of new forms resistant to insect enemies, however, has scarcely made a beginning.

The need for the work is clear enough. Besides the losses we have incurred, in some regions of the United States forest planting is coming into use as the surest and quickest method of reproducing the desired wood crops. Planting makes it possible to control the kind and variety of tree that occupies the site and gives special emphasis to the need for careful selection of the planting stock. It costs no more to plant the resistant trees, if they are available, than to plant ordinary stock.

In the development of trees resistant to a particular disease or insect enemy, the same principles of selection and genetics apply that are employed in the development of new, vigorous, and fast-growing tree forms. The tree breeder, however, usually desires both resistance and vigor in his final selection, but when the laws of heredity decree differently, the breeder faces a difficult problem. The solution of such problems requires knowledge of several sciences, especially genetics, plant pathology, entomology, and forestry.

The breeder first attempts to select trees that show resistance to the particular pest under study. Resistant selections are propagated by grafting or by cuttings. Seed from such selections is collected and thousands of seedlings are grown in nurseries where they may be tested against the pest, or the seedlings may be transplanted to testing plots where they can be tested at a more suitable age.

Sometimes selection results indicate that no individuals of the particular species or of related species are resistant. It is then necessary to import seed of foreign species for testing. The related foreign species, however, may possess no worthy characteristic other than that of resistance. The breeder must combine this character of resistance with the desirable characters of the susceptible species. The first step to bring about this combination is to produce a hybrid by crossing a resistant tree with a susceptible tree.

Hybrids obtained from the first crossing of two varieties or species are known as first filial (F_1) generation hybrids. If an F_1 tree sets seed by its own pollen (selfing), or if two or more F_1 trees are crossed with one another (sib-mating), the resulting hybrids belong to the second (F_2) generation. The F_2 and subsequent generations are called the segregating generations because all the characters, visible and invisible, that were present in the F_1 trees segregate out among the various trees of the later generations.

RESISTANCE to a pest may be inherited in one of three ways. If resistance is inherited as a dominant character, all the F_1 trees will be dominantly resistant and most of the F_2 trees will be similarly resistant. Resistance may be inherited as an incomplete dominant, in which instance the F_1 trees will be more or less intermediate in their resistance to the pest. The F_1 trees as a group will not show the resistance of the resistant parent nor the susceptibility of the other parent. In this type of inheritance the second and subsequent generations will produce a lower proportion of resistant trees than the first type of inheritance produces. If the breeder meets either one of these types of inheritance, he will have comparatively little difficulty in obtaining trees with a satisfactory degree of resistance. But susceptibility may be inherited as a dominant character. The first-generation trees will be susceptible and will have no value except for further breeding to obtain second-generation trees. The second generation in this instance must consist of large numbers of trees because the proportion of resistant specimens will be exceedingly small.

In agricultural crop breeding, the breeder usually fixes the type by inbreeding so that it reproduces more or less true from seed. The tree breeder cannot afford to fix his hybrid types.

Tree hybrids usually lose vigor when inbred, and the process of inbreeding trees requires too long a time. When the tree breeder obtains maximum resistance in his hybrids in combination with other desirable characters, he is ready to plant them on appropriate sites for final testing. Since his hybrids, in general, will not breed true, the question arises as to the nature of the progeny from these hybrids when they are planted in the wood lot and in the forest. Part of the progeny may be resistant but not vigorous, another part may be vigorous but susceptible, and another part may be both vigorous and resistant. The tree breeder can determine the theoretical proportions of these progeny types because he knows the way in which characters are inherited in the species with which he works.

Each tree-breeding project presents problems of its own. Examples of experimental work will be described to illustrate various methods of testing trees for resistance to particular pests, and to indicate the progress that has been attained. However, most of the selecting and breeding of trees for resistance to pests is still exploratory—in only a few instances hybrids have been developed to the stage that permits planting them as replacements for their inferior parents.

WHITE PINES RESISTANT TO BLISTER RUST: A. J. Riker and associates at the University of Wisconsin, in cooperation with the Department of Agriculture, have tested selections of eastern white pine against the blister rust. One thousand grafts were made from 163 trees selected for their resistance to heavy natural infection for more than 15 years or for other special properties. Most of the grafts resisted artificial infections of the blister rust fungus. However, when 10,000 seedlings from the selected trees and commercial seedlings were subjected to natural and artificial infections, a high percentage of the seedlings were infected with stem cankers within a year. Ray R. Hirt of the New York State College of Forestry, in cooperation with the U. S. Department of Agriculture, observed eastern white pines of various ages in the period of 1927–47 for resistance to the rust. He found varying degrees of rust resistance in a small percentage of the total pines observed. Those trees showing greatest resistance to rust are being propagated by grafting and cuttings so that more extensive tests for resistance can be made. The low percentage of rust-resistant seedlings reported by Riker and Hirt indicates that rust resistance is not inherited as a dominant character.

The white pine blister rust fungus also attacks other five-needle species of pine. Forest pathologists are keenly interested in determining the relative susceptibility of native and exotic species of pine to the fungus. Seven species of pine were tested against rust by Ray R. Hirt, of the New York State College of Forestry; in the Northwest, nine species were tested by Thomas W. Childs and Jess L. Bedwell, of the Division of Forest Pathology.

The species of pine that showed resistance to blister rust were: *Pinus cembra* var. *helvetica, P. armandi, P. griffithii,* and *P. koraiensis*—all are foreign species but are not known to have any timber value. Those showing susceptibility in increasing degrees were: *P. aristata, P. peuce, P. ayacahuite, P. flexilis, P. monticola, P. albicaulis,* and *P. lambertiana.* Several trees of the latter species, commonly called sugar pine, have withstood infections from blister rust for 14 years and will be used as breeding and propagating material.

RESIN MIDGE: In the blister rust experiments, inherent resistance of selected pines was determined by inoculation tests. In the case of an insect parasite, the resin midge, we find that an external characteristic of the trees—new shoots with dry, smooth bark—is an indicator of resistance. The problem was approached by selecting for this particular character.

Resin midge resistance studies were carried on from 1930 to 1940 at the Institute of Forest Genetics, near Placerville, California. This undescribed species of resin midge (*Retinidiplosis* sp.) caused considerable damage to young planted ponderosa pines at the Institute and to natural reproduction throughout much of the western pine region during this period. The feeding habits of the larvae cause resin-filled pits in the thin bark of the stems and twigs, and these pits result in growth deformities and dwarfing of the trees. In time the heavily injured trees die.

A study of the stem characteristics of many trees revealed that the heavily infested trees were those that produced new shoots covered with a sticky, resinous film, a growth character of certain trees. Noninfested trees were those that produced new shoots with dry, smooth bark. The data collected showed that only 11.2 percent of the sticky-stemmed trees escaped injury, while 93.4 percent of the smooth-stemmed trees escaped injury entirely or were only lightly attacked. The next phase of these investigations will be to determine whether dry, smooth bark is inheritable and, if so, to produce trees with this characteristic for reforestation purposes.

RESISTANCE TO WEEVIL: Resistance in pine to another parasitic insect, a weevil, was obtained by crossing a resistant with a susceptible species. The insect (*Cylindrocopturus eatoni*) is the most important enemy of young planted pines in the brush fields of northern California where, in some areas, it killed 90 percent of the trees within 10 years after planting. It also killed natural reproduction that was restocking burned-over pine areas. The trees are killed by the larval mines that extend through the phloem and cambium areas and later into the wood. In nature, the weevil's preferred hosts are ponderosa pine and Jeffrey pine. A number of other species of pines, such as Coulter pine and sugar pine, appear to be immune to its attacks.

Studies were begun at the Institute of Forest Genetics in 1946 to determine whether a resistant variety of pine could be developed that would have the same desirable wood qualities as ponderosa and Jeffrey and at the same time survive weevil infestations during the early years of growth. A number of species, hybrids, and varieties of pines were tested by forcing the attacks of the weevil on them under cage control. Among the trees tested was a new hybrid pine first produced by geneticists at the Institute in 1939 by crossing Jeffrey pine with a natural hybrid of Coulter pine.

The tests confirmed field observations that ponderosa and Jeffrey pines were generally susceptible to the weevil although some trees proved to be resistant. The Coulter pine was uniformly resistant as was also the Jeffrey-Coulter hybrid. Here we have indications of resistance to insect attack being inherited as a dominant character, not only in the first generation hybrid but also in the backcross of this hybrid on the susceptible Jeffrey pine.

ELMS RESISTANT TO THE DUTCH ELM DISEASE: The Dutch elm disease, which was discovered in this country in 1930, now threatens all native and European elm species in the United States. Elm bark beetles spread the disease.

Efforts to control the disease include destruction of infected trees, pruning infected limbs, and destroying, debarking, or spraying elm logs.

The American elm is an important forest and shade tree, native to parts of all States from the Great Plains eastward to the Atlantic coast. Two minor species, also native, are the rock elm and the slippery elm, both susceptible to the Dutch elm disease. The Siberian elm is resistant.

In 1937, scientists in the Division of Forest Pathology began breeding and selecting elms for resistance to the Dutch elm disease. Thirty-five thousand elm seedlings, collected in the Great Plains and Northeastern and

Central States, were grown in test nurseries. The seedlings were inoculated with the Dutch elm disease fungus, with the result that only two seedlings withstood inoculations in three consecutive seasons.

The American, Siberian, and rock elms bloom in the early spring, and low temperatures and strong winds are not conducive to delicate manipulations of the flowers or favorable to pollination and seed setting. A difference in chromosome numbers leads to further difficulties in obtaining progeny in large numbers. From about 20,000 controlled American-Siberian elm crosses, fewer than 100 seed were obtained, and only a fraction of those germinated. Of the hybrids obtained, one has resisted repeated inoculations with the Dutch elm disease fungus.

In 1939 some specimens of a European elm, selected for their resistance to the disease, were imported. They have retained their high degree of resistance but have failed to grow as rapidly as American elms nearby, and they do not have the characteristic shape of the American.

CHESTNUT TREES RESISTANT TO BLIGHT: The chestnut blight was discovered in New York City in 1904, and within 40 years all American chestnut stands from Maine to northern Georgia and westward to Ohio, Kentucky, and Tennessee were killed.

So far as the American chestnut is concerned, there is no control for the blight. This chestnut apparently is completely susceptible to the blight fungus. Even today there are few seedlings or sprouts that appear to be resistant.

Large-scale introductions of blight-resistant species of chestnuts from the Orient were necessary for an effective breeding program. The early breeding work of Walter Van Fleet was limited to a few introductions of the Chinese and Japanese chestnuts. Hybrids of these and the American chestnut usually died from the blight a few years after bearing.

In the breeding program, continued since 1925 by Russell B. Clapper, the present objective is to obtain the maximum vigor and resistance to blight in the first-generation trees derived from crossing the American chestnut with proved selections of Chinese chestnut. One lot of first-generation trees in Maryland grow an average of 2¾ feet a year and have considerable blight resistance. New combinations of American and Chinese chestnut are being produced for testing. Natural-crossing plots, where the American will cross naturally with a proved Chinese chestnut, will be established for the production of hybrid seed in quantity.

A number of the Chinese-American chestnut hybrids have been backcrossed to the resistant Chinese parent trees. The resulting backcross generation shows somewhat less vigor and, in some instances, poor stem form, when compared with the first-generation trees. They have practically the same degree of blight resistance, however, as the Chinese parent trees.

The Brooklyn Botanic Garden, in cooperation with the Department of Agriculture, began breeding chestnuts in 1930. Arthur H. Graves has headed the project. His objective also is to obtain a superior blight-resistant forest tree to replace the American chestnut. Promising hybrids, some with genes from the Japanese chestnut, some with genes from the Chinese chestnut, and others with genes from both species, are being tested on the same forest sites along with hybrids produced by the Division of Forest Pathology.

From about 1930, seedlings of the Chinese and Japanese chestnuts were available in large numbers, and experimental forest plantings were established under many varied site, soil, and climatic conditions, with varying degrees of success. With few exceptions, the Chinese chestnut appears to be superior to the Japanese chestnut in blight resistance, rate of growth, and stem form. Planted in the most favorable environments, the Chinese chestnut shows promise of making a fair timber tree.

The Division of Forest Pathology now is establishing the best strains of Chinese chestnut on the best types of sites, so that there will be permanent sources of seed for dissemination and distribution. Cooperators' plantings already are furnishing valuable seed for these plantings.

OTHER BREEDING AND SELECTION WORK: From 1930 to 1941 studies by R. C. Hall and others of the Forest Insect Laboratory at Columbus, Ohio, revealed that two recognized varieties of black locust were resistant to attacks of the locust borer, *Megacyllene robiniae* (Forst.). This borer has caused widespread damage to black locusts in the eastern part of the United States. From eggs deposited in bark crevices, the young larvae mine the inner bark and cambium. Later the mines are extended into the sapwood and eventually into the heartwood. Tests made on one of the resistant varieties, the Higbee locust of southern Indiana, showed that about 95 percent of the larvae planted in the bark crevices started mines in the inner bark, but only about 20 percent reached the wood and matured there. In susceptible locust varieties, practically all the planted larvae mined the inner bark and lived to the adult stage.

In 1924 the Oxford Paper Company, in cooperation with the New York Botanical Garden, began a poplar-breeding project. Approximately 13,000 hybrids were produced by crossing 34 different types of poplars. A number of plantations have been established in the eastern part of the country and the poplars are being observed for their reactions to various diseases. A. J. Riker, of the University of Wisconsin, is also testing hybrid poplars and selections of the native poplars for their qualities, including resistance to various diseases. The Division of Forest Pathology is inoculating various poplar hybrids in an attempt to obtain one that is resistant to Septoria canker and other diseases.

The mimosa is an important shade and ornamental tree in the South. A wilt disease was discovered on mimosas in 1935; since then the disease has killed entire plantings and threatens many more. Search for resistant trees started in 1939. Hundreds of seedlings, grown from seed collected from Maryland to Louisiana, were inoculated with the wilt fungus, with the result that 20 seedlings remained wilt-free. These will be crossed with one another in an attempt to get better and more resistant mimosas.

Selections of elms are being investigated by Roger U. Swingle, of the Division of Forest Pathology at Columbus, Ohio, for resistance to the virus disease, phloem necrosis. From an area where the disease has occurred for more than 50 years, about 2,000 trees that were selected from open-pollinated stock have shown high resistance to the virus. The more resistant trees are being propagated by root cuttings.

Workers in the Arnold Arboretum, Jamaica Plain, Mass., are breeding species of pines for timber purposes and are selecting from first- and second-generation hybrids for resistance to insects and diseases. They are also crossing two Oriental species of elm, *Ulmus japonica* and *U. wilsoniana*. Hybrids of those species are resistant to the elm leaf beetle.

FEDERAL, STATE, AND PUBLIC PARKS nurserymen each year plant millions of tree seedlings. The seedlings are derived from seed that came mostly from trees that are susceptible to attacks of various insects, fungi, and viruses. The planted trees will likewise be subject to attacks of these pests, resulting in the partial or total loss of time and effort of many years. One prime objective of the tree breeder is to develop forms resistant to pest attacks and to multiply those forms so that they will be available in quantities for distribution and planting. Both phases of this objective usually require many years of work. Although nature successfully replants tree species generation after generation, man is learning more and more about how to do the job with better trees.

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JOHN M. MILLER, *a senior entomologist, conducts research and control investigations in the Forest Insect Division, Bureau of Entomology and Plant Quarantine. He has been with the Department of Agriculture since 1910. Since 1945 he has been conducting studies dealing with the resistance of new pine hybrids at the Institute of Forest Genetics, near Placerville, Calif.*

THE AIRPLANE IN FOREST-PEST CONTROL

J. S. YUILL, C. B. EATON

The airplane has become a new weapon in the never-ending battle against destructive forest insects. As in military operations, it is bringing about radical changes in strategy. Aircraft are serving two purposes in this phase of forest protection: For detection surveys to locate serious insect outbreaks and for the application of insecticides to control dangerous infestations.

The extent to which those operations can be carried on from the ground is seriously limited because the areas involved are often large and remote, and because the cost of ground operations in forests is high, even under the most favorable conditions. Many outbreaks of insects in the past consequently have had to be allowed to run their natural course until eventually they were checked by exhaustion of the food supply, changes in weather conditions, increase in the abundance of natural enemies, or other factors. But, in contrast to ground equipment, airplanes can cover large and isolated areas quickly and in most cases at a reasonable cost. Although improvements must be made in equipment and procedures to develop aerial methods for extensive general use, the progress since the Second World War has been encouraging.

Finding the enemy, estimating the numbers, and determining the rate of movement are as essential in combating insect outbreaks as in conducting a successful military campaign. The Bureau of Entomology and Plant Quarantine, in cooperation with various Federal, State, and private agencies, carries on extensive surveys each year to obtain such information for planning control operations. The work commonly includes cruising representative sample plots; reconnaissance inspections by truck, horseback, or foot; and visual examination from mountaintops or other vantage points. Obviously, the surveys are limited by the relatively small proportion of total forested area that can be covered in a season. In the search for better and faster methods, the idea was advanced that if the observer could use a moving observation point—an airplane—instead of a mountaintop he could cover much more territory in a day.

THE FIRST AIR SURVEYS of defoliating insects were conducted in Canada in 1922 and 1923. In a week, air-borne observers mapped several thousand square miles seriously defoliated by the spruce budworm; by ground methods, that work would have taken 3 to 4 months. In following years, limited air surveys were made in both Eastern and Western States to detect and map several other insect outbreaks. The